THE STATE OF NEW HAMPSHIRE

BEFORE THE

NEW HAMPSHIRE SITE EVALUATION COMMITTEE

DOCKET NO. 2015-06

SUPPLEMENTAL PRE-FILED TESTIMONY OF NATHAN SCOTT

IN SUPPORT OF THE
APPLICATION OF NORTHERN PASS TRANSMISSION LLC
AND PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE
D/B/A EVERSOURCE ENERGY
FOR A CERTIFICATE OF SITE AND FACILITY TO CONSTRUCT A NEW HIGH VOLTAGE TRANSMISSION LINE AND RELATED FACILITIES IN NEW HAMPSHIRE

April 17, 2017

Q. Please state your name, title, and business address.

A. My name is Nathan Scott. I am a Senior Transmission Engineer for Burns & McDonnell Engineering, Inc. My current business address is 9400 Ward Parkway, Kansas City, Missouri 64114.

Q. What is the purpose of your supplemental testimony?

A. The purpose of my supplemental testimony is to provide additional information to the New Hampshire Site Evaluation Committee ("NHSEC" or "Committee") regarding the underground design of the Northern Pass Transmission Project (the "Project") as proposed by Northern Pass Transmission LLC and Public Service Company of New Hampshire d/b/a Eversource Energy ("PSNH") (collectively the "Applicants").

Q. Has your role in the Project changed since your pre-filed testimony was submitted?

A. As initially described in my Pre-Filed Direct Testimony dated October 16, 2015, Burns and McDonnell was contracted by NPT to be the underground project manager and lead engineer responsible for the electrical design of the three underground segments of the high-voltage direct current ("HVDC") transmission line for the Project. Since that time, my specific duties have changed due to modifications in the contractual relationships between NPT, Burns and McDonnell, and the Project's lead contractor, PAR Electrical Contractors, Inc. ("PAR"). Today, I remain the lead underground engineer; however, my role has shifted from designing the underground portions of the project to the review, on behalf of NPT, of the design being prepared by PAR.

As described by Mr. Kenneth Bowes in his supplemental pre-filed testimony, Burns & McDonnell will be retained as the Owner's Engineer when the Project transitions from the siting and permitting phase to the execution and construction phase of the Project. The detailed design for the underground installation will be completed by PAR. In the construction and execution phase, I will support Northern Pass as the lead underground engineer acting as the Owner's Engineer. In this role, I will review the final detailed design prepared by PAR and its design sub-consultant(s) for the underground segments of the Project. I will also review design documents prepared by ABB related to the underground cable system.

Q. Have there been any changes to the underground design since your Pre-filed Direct Testimony was submitted in October 2015?

A. Yes. Additional utility and topographic surveys have been completed for the entire length of the proposed underground installation. The results of these surveys have been incorporated into the December 2016 filings, namely the detailed design packages prepared for the New Hampshire Department of Transportation ("NHDOT") (App. Ex. 73), also available on the NHSEC Website.

The utility survey consisted of utilities record research, GIS information, as well as field verification of locations of above grade facilities as well as gravity inverts. The level of subsurface utility investigation completed is in accordance with Subsurface Utility Engineering Quality Level C (SUE QL-C). Geotechnical investigation and summary reports by Haley & Aldrich as well as Terracon have been completed for the entire length of the proposed underground installation. Although the plan and profile drawings for the underground portion of the Project may look similar to that developed when my Pre-filed Direct Testimony, dated October 16, 2015, was submitted as a part of the Application at Appendices 9 and 10, the design is undergoing revisions to address comments from NHDOT.

Q. Please describe the status of the Applicants' permit applications to the NHDOT.

A. On April 3, 2017, the NHDOT issued a final decision titled Recommended Approval with Certain Permit Conditions, which I have reviewed. The Applicants anticipate further ongoing coordination with the NHDOT to finalize a design that satisfies the permit conditions of the NHDOT approval.

Q. What modifications have been made to the underground design based on comments and feedback from NHDOT to-date?

A. The modifications that have already been made are based upon coordination with the NHDOT and include modifications to the centerline of the alignment and alterations of splice enclosure locations to the edge of the road or out of the traveled lane wherever possible. The trench cross sections have had minor modifications made as well, with different configurations of the materials in the trench depending upon the location within the roadway or edge of road and depth of installation. This is further addressed below. Trenchless design coordination with the NHDOT is ongoing and may require modifications to the design for certain crossings.

As coordination with NHDOT continues, further adjustments to the design will be made that will determine where within the road right-of-way the proposed underground installations will be located. The design has also been updated to account for the detailed design of the trenchless installation locations. For many of these trenchless installations, the Project and NHDOT have determined that separate bores will be utilized; one bore for each power conduit. The separate bores will help with cable ratings as well as minimize the size of equipment required to perform the work.

Q. Has the Project performed additional analyses related to the underground design since your pre-filed testimony?

A. Yes. The Project has performed additional geotechnical investigation that has been used to verify the civil installation required to install the cable system and maintain the circuit ratings. Additionally, the geotechnical investigation has been used to further develop the trenchless installation design.

Q. Are there any additional changes that may take place to the design that have not been shown in the Project design to date?

A. Yes. As the Applicants continue to work with NHDOT to finalize an underground design that conforms to the permit conditions the trench cross sections may be updated. However, the previously identified materials in my pre-filed testimony (thermally approved fluidized thermal backfill, native backfill, or thermally designed concrete) will remain the same. In addition, detailed trenchless design has already adjusted the lengths as well as the start and end locations of the trenchless installations.

Continued coordination with NHDOT and the finalization of the trenchless design will likely result in the underground alignment of the Project moving closer to the edge of the road or outside of the traveled lane wherever agreed upon between the Project and the NHDOT.

Q. Is NPT able to design and construct the Project entirely without using private property not currently owned by NPT or an affiliate of NPT?

A. Yes. In addition, Condition #10 of the NHDOT Approval provides that the NHDOT “cannot and does not grant [the Applicants] permission to enter upon or use any privately owned land.”

Q. Has the number of trenchless installations and associated splice locations changed since your October 2015 pre-filed testimony?

A. Yes. The Route 3 River Crossing Alignment from Pittsburg to Clarksville has one (1) proposed HDD and one (1) proposed splice location. The Northern Alignment (NRTH) from Clarksville to Stewartstown has six (6) horizontal directional drills (HDD's) and one (1) horizontal bore (HB) proposed as well as twenty (20) proposed splice locations. The Bethlehem to Bridgewater Alignment (BB) has forty-one (41) proposed HDD's and one (1) proposed HB as well as one-hundred and thirty-eight (138) proposed splice locations.

Q. Please explain why the number of trenchless installations and associated splice locations has changed.

A. After utility surveys and geotechnical investigations were completed, PAR and its subcontractors commenced reviewing and developing the detailed design for the Project. As a result of the detailed design process, certain adjustments were made to the alignments and locations where trenchless installations are proposed. The locations of proposed splice enclosures have also been adjusted to account for the information gathered from the utility survey and the locations of the proposed trenchless installations as modified during the detailed design process.

Q. Do you have any updates or additional information about the selected cable for this Project?

A. The selected cable vendor, ABB, has reviewed the geotechnical investigation results and performed ampacity calculations to verify the civil cable trench cross sections will meet cable ratings. ABB has prepared a study titled *Cable Interaction with Soil Temperature Analysis at 32°F* on 12/15/2016, Attachment A. This study describes the negligible impacts to surface freeze conditions that the addition of the heat source of the cable system will have underneath the traveled roadways.

Q. Are there any specific maintenance issues that you are aware of?

A. Once the civil infrastructure and the cable systems have been installed, there will be minimal to no maintenance under normal operating conditions. Maintenance of the transmission system would only occur in the event of a failure on the cable system. Cable system failures are rare, and are typically at splice or termination locations. A failure in the cable system would require location of the failure, opening of the splice pits at either end of the failure location, removal of the failed cable/splice, installation of a new cable/splice, and civil restoration of any disturbed area.

Q. Have you reviewed the Dewberry Report? Do you have any comments to make at this time?

A. Yes, I have reviewed the Dewberry Report. The Dewberry Report highlights many of the design/construction elements that require ongoing coordination with the NHDOT. As detailed design progresses to issued-for-construction (IFC) level of design, the Applicants will continue to coordinate with the NHDOT and any design changes made to reflect such coordination with NHDOT will be included in the IFC package.

Q. Have you reviewed the ECE Underground Report? Do you have any comments to make at this time?

A. Yes, I have reviewed the ECE Underground Report. The ECE Underground Report highlights many of the design/construction elements that require ongoing coordination with the NHDOT. As detailed design progresses to issued-for-construction (IFC) level of design, the Applicants will continue to coordinate with the NHDOT and any design changes made to reflect such coordination with NHDOT will be included in the IFC package. Laydown space proposed for trenchless installations are shown on the detailed trenchless design drawings prepared by Brierly Associates, as well as reflected in the traffic control drawings.

Q. Does this conclude your supplemental pre-filed testimony?

A. Yes, it does.

Cable Interaction with Soil Temperature Analysis at 32° F 12/15/2016

The NHDOT has expressed concern that the placement of the NPT underground power cables will create an adverse surface condition on roads directly above the cable placement. The concern from the NH DOT as we understand it is because the cables are warmer than the surrounding soil during operation and that this heat could potentially melt the ice lying on the ground surface above the cables faster than the surrounding ground surface creating a liquid water area near the adjacent ice laying on the ground. For the reasons described below, the cable will have negligible impact on the surface temperature.

The concern could stem from the fact that the maximum operating temperature of the power cable has been explained to be 70 °C (158 °F). This cable temperature only occurs when the cable system is operating in the warmest part of the season (typically late summer) and operating at full load. The heat is generated in the cable due to electrical current flowing through the conductor. The conductor has a physical parameter called electrical resistance. When current flows through the conductor the electrical resistance will create heat (measured in watts) in the conductor. All the heat will dissipate from the conductor to the surface of the ground. This will create a temperature gradient from the conductor to the surface of the ground.

Figure 1 shows this temperature gradient for the highest conductor temperature condition where the cable is at a maximum temperature of 70 °C, the soil temperature is at 15.8 °C (60.4 °F) and the surface is at 21.4 °C (70.5 °F). The colored lines indicate lines of constant temperature and are shown in 1 degree increments. The soil conditions for the model below are for a native soil thermal resistivity of 2.0 K-m/W and the trench is backfilled to the top with Fluidized Thermal Backfill (FTB) that has a maximum thermal resistivity of 1.0 K-m/W. This combination produces the tightest temperature gradient. The temperature gradient at the surface of the trench is approximately 8.5 degrees C per foot of depth. The numbers on the graph represent the temperature of the line it sets over such as 30 degrees.

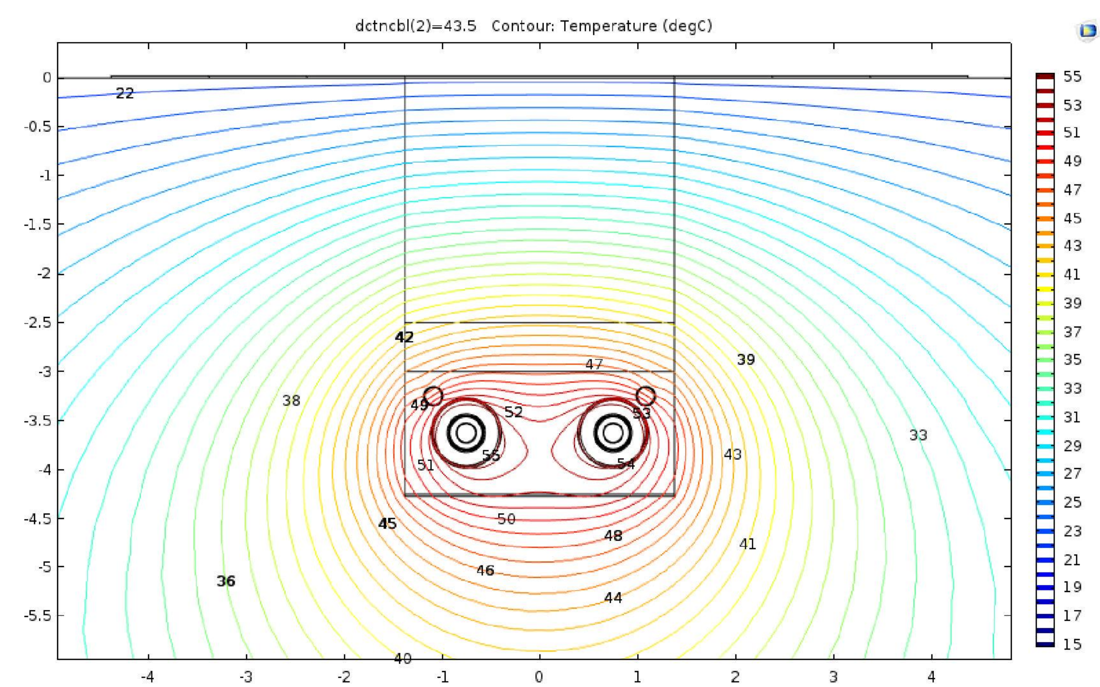

Figure 1

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The heat generated by the cable will dissipate to the surface because the surface of the earth is cooler than the core of the earth. Soil has a thermal inertia and a thermal resistance to heat transfer which creates a time lag for the soil to change temperature as the air temperature changes. The daily variation in air temperature only affects the soil temperature down to 1 or 2 inches below surface.

At soil depths greater than 33 feet (10 meters), the soil temperature is relatively constant, and corresponds roughly to the water temperature measured in groundwater wells 30 to 50 feet deep. This is referred to as the "mean earth temperature." Figure 2 shows the mean earth temperature contours across the United States in degrees Fahrenheit. You can see in the chart below that the mean earth temperature for New Hampshire ranges from 42 °F (5.5 °C) in the north of the state to around 47 °F (8.3 °C) in the southern part of the state.

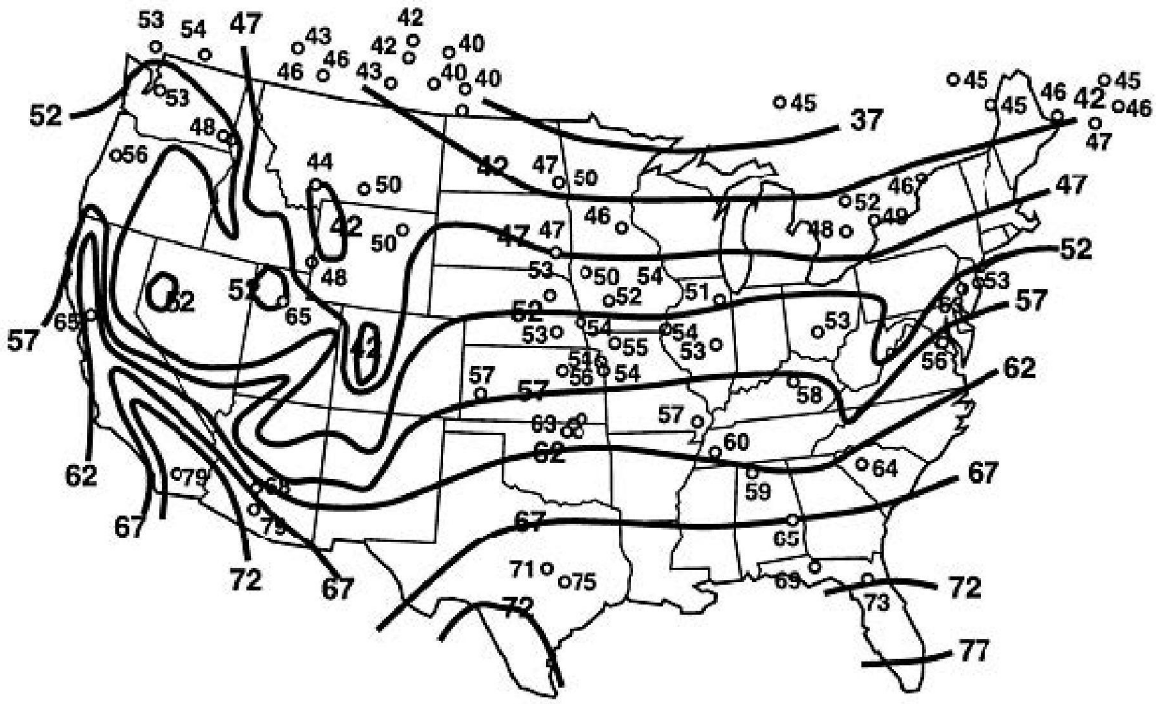

Figure 2

Soil temperature varies from month to month as a function of incident solar radiation, rainfall, seasonal swings in overlying air temperature, local vegetation cover, type of soil, and depth in the earth. Due to the much higher heat capacity of soil relative to air and the thermal insulation provided by vegetation and surface soil layers, seasonal changes in soil temperature deep in the ground are much less than and lag significantly behind seasonal changes in ambient air temperature. Soil temperatures lag the air temperature.

Figure 3 assumes the average maximum air temperature to be a maximum in July. The soil temperature at 1 meter below surface is lagging the air temperature and does not have as high a maximum temperature or as low a minimum temperature as the air. The lag in the soil temperature is controlled by the thermal resistivity of the soil (how well the heat moves through the soil) and the depth. The deeper the soil the longer the lag and the smaller the magnitude of the variation until the soil temperature reaches the constant mean earth temperature.

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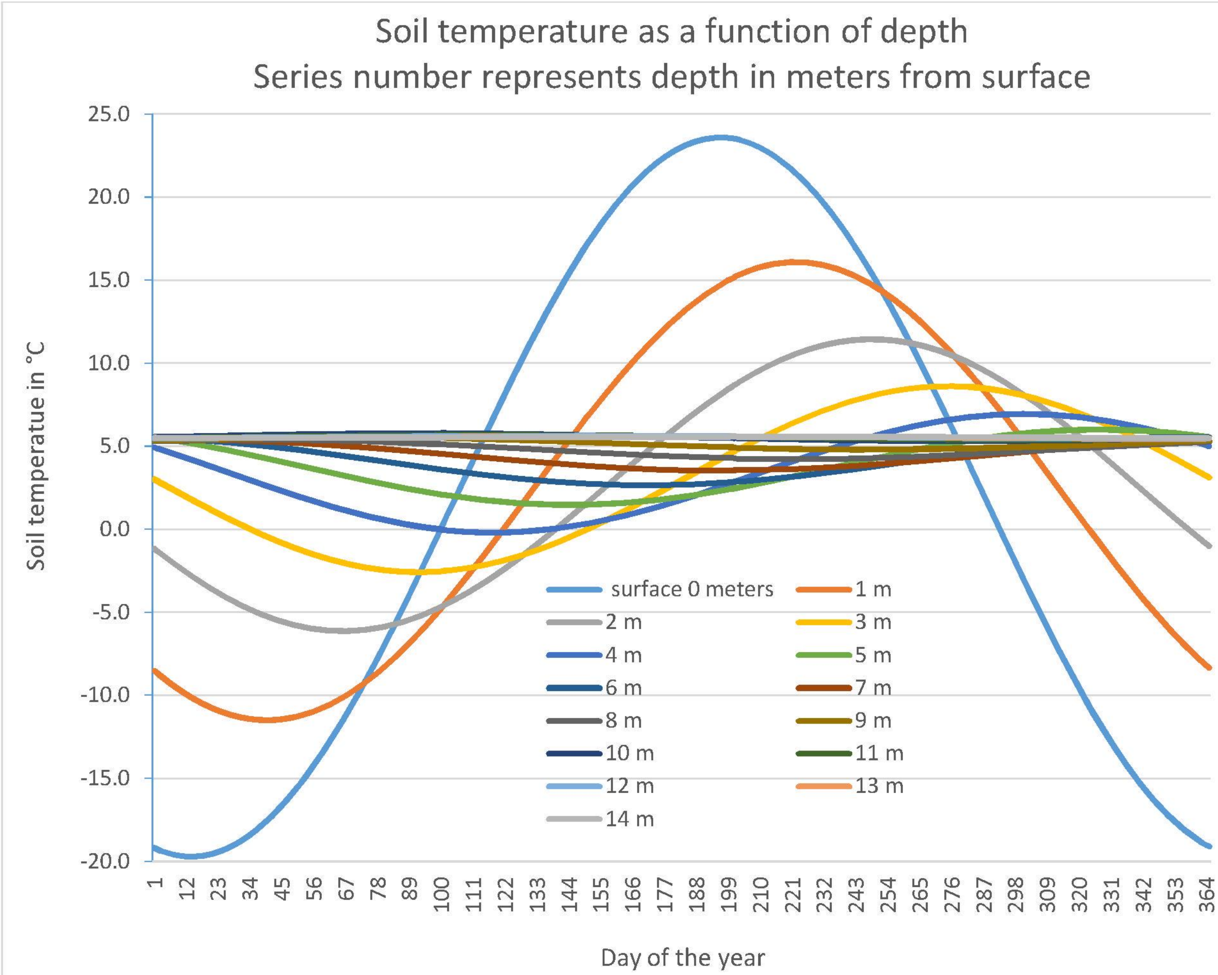

Figure 3

From just below the surface to approximately 10 meters (33 feet) depth, the soil temperature will vary sinusoidally and be a function of the average annual high and low air temperatures and the mean earth temperature. The soil temperature sinusoidal variation will flatten out as the depth gets deeper. See Appendix 1.

Figure 4 below shows the seasonal variation of the air temperature at the surface of the ground (in blue) and the corresponding variation of the soil temperature at the shallowest burial depth (43.5 inches to center of conduit) of the cable system (in orange). Because of the thermal inertia of the soil and the thermal conductivity of the soil there is a time delay of the soil temperature at burial depth relative to surface of the ground. The Figure 4 shows the undisturbed soil temperatures without any heat source (such as the cable system) and is based on the average annual high air temperature and the average annual low air temperature. For this analysis it was assumed that the maximum average high air temperature occurred in July and the low occurred in January. The soil temperature at burial depth lags the surface temperature by about 22 days based on soil thermal resistivity of 1.0 K-m/W. The gray line indicates the soil temperature at approximately 10 meters (33 feet) and below.

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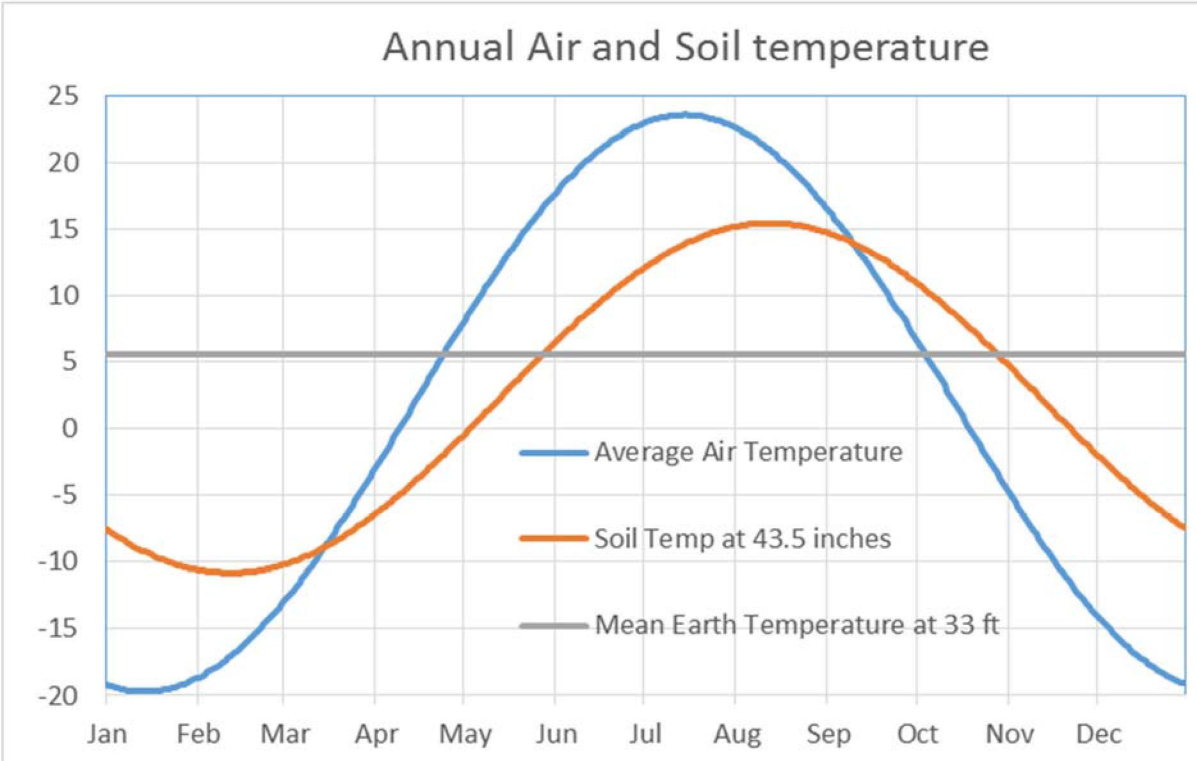

Figure 4

Water Freezes at 0 °C and below and if ice is present it will start to melt as the temperature rises from below 0 °C to warmer temperatures. For the analysis as it relates to New Hampshire, it is assumed that twice a year the surface temperature is transitioning across the 0 °C zone, fall and spring.

As was discussed earlier in the report, the cable system has a maximum conductor design temperature limit of 70 °C. This maximum conductor temperature occurs in the summer. In the winter, when the soil is much cooler, the conductor temperature will be much lower even while operating at the same maximum design current. The heat generated in the conductor will be moved to the surface by thermal conduction. Figure 5 below is a plot showing lines of constant temperature in the soil while the surface is just below freezing. The soil temperature at burial depth is lagging the surface temperature so it is actually warmer than the surface. This is at its worst case in the fall season when the surface is at freezing and the soil is warmer. The analysis is done assuming the surface is just at 0 °C and the soil at burial depth is approximately 7.7 °C (45.8 °F). Under these conditions with the below soil characteristics the maximum conductor temperature is 45.0 °C. This analysis assumes a native soil thermal resistivity of 2.0 K-m/W and that the trench is backfilled to the surface with FTB that has a maximum thermal resistivity of 1.0 K-m/W. These values were used to have comparable models.

Figure 5 shows the conditions for the fall season to estimate the impact on the ground surface temperature in the vicinity of the cable system. It can be seen that the temperature gradient is about 7 °C / foot near the top of the trench which will not have any perceptible impact on the melting rate of ice relative to the other areas away from the cable installation. The soil temperature within two inches of the surface is directly impacted by the ambient air temperature. As previously discussed, the air temperature variations will be changing faster than the constant

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soil temperatures due to the heat from the cable and will allow for either melting or freezing of water on the surface. Any temperature differential between the air and the first few inches from the soil will be equalized by the air or ice above the surface and the surface should remain at a temperature within a degree of the surface conditions.

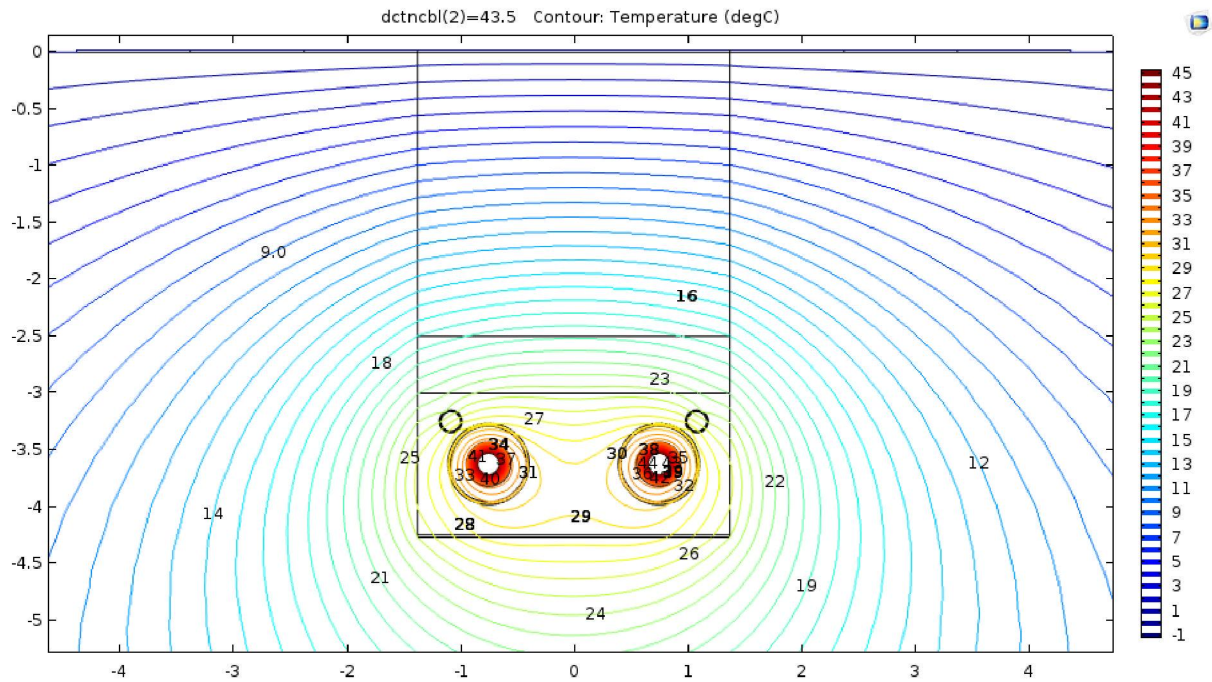

Figure 5

It cannot be assumed that there will not be some special condition where the air temperature is changing so fast that the soil holds a temperature different than the air and a potential for ice to form or ice to melt could happen but this will be for a short time period and the surrounding soils will be experiencing the same temperature difference.

Also, of note is that the potential for frost heave being caused by cable system being warmer than the surrounding soils is negligible. Because the mean earth temperature is warmer (at least in the USA) than 32 °F (0°C), the ground will freeze from the surface down. In the vicinity of the cable, the soil will be warmer than the surrounding soil. The area of soil at the sides of and within a few inches above the cable duct along the route will be the last to freeze (if it freezes at all) and the first to thaw due to the heat generated in the cables and the mean earth temperature below the cables being above freezing.

The area below grade surrounding the cable will be warmer than the outwardly surrounding conditions and as such water will be fluid and mobile around the cables longer than the surrounding soil and will freeze last and thaw first before the surrounding soil preventing frost heaves being caused by the cable system. Any liquid water will be pushed downward as the soil freezes from the surface down.

In essence, there will be no perceptible impact on surface or subsurface conditions relative to cable installation.

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Appendix 1

The derivation of temperatures of ground as a function of the air temperature variation is derived in:

Introduction to the
MATHEMATICAL THEORY OF THE CONDUCTION OF HEAT IN SOLIDS
By H. S. CARSLAW
DOVER PUBLICATIONS
New York 1945

Based on the derivation from above and taking into consideration the measured mean earth temperature a formula for soil temperatures was derived. The formula for the temperature of the soil at a burial depth over the course of a year between the surface and the mean earth temperature (33 feet) is a function of the minimum and maximum average annual air temperature and the mean earth temperature defined above. The formula is:

$$\theta(x,t) = \theta_{mean} + \frac{\Theta_{Earthmean} - \theta_{mean}}{d_{Earthmean}} * x + \frac{\theta_{max} - \theta_{min}}{2} e^{-x\sqrt{\frac{\omega}{2k}}} \cdot \sin\left(\omega t - x \cdot \sqrt{\frac{\omega}{2k}} - \beta\right)$$

Where:

θ_{max} °C	= maximum temperature of surface (average annual high air temperature)
θ_{min} °C	= minimum temperature of surface (average annual low air temperature)
θ_{mean} °C	= the average of the maximum and minimum air temperature
$d_{Earthmean}$ (m)	= the distance from the surface where the soil temperature is constant and equals $\Theta_{Earthmean}$
$\Theta_{Earthmean}$ °C	= mean earth temperature measured at 30 to 50 feet for a local area.
x (m)	= depth at which temperature is calculated
k m^2/s	= diffusivity of ground
ρ K×m/W	= thermal resistivity of ground
c Ws/K×m^3	= specific heat of ground
β rad	= arbitrary angle
t seconds	= time over the course of a year in seconds

The diffusivity is defined as:

$$k = \frac{1}{\rho \cdot c} \quad \frac{m^2}{s}$$

The angular velocity is defined:

$$\omega = \frac{2\pi}{365 \cdot 24 \cdot 3600} \qquad \frac{rad}{s}$$

The angle β determines the time when maximum temperature θ_{max} during the year reaches its maximum.

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